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UNITED STATES
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HAROLD L. ICKES, SECRETARY

BUREAU OF MINES
JOHN W. FINCH, DIRECTOR

INFORMATION CIRCULAR

A TECHNIQUE FOR USE OF THE IMPINGER METHOD

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BY

CARLTON E. BROWN AND H. H. SCHRENK

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

A TECHNIQUE FOR USE OF THE IMPINGER METHOD[1]

By Carlton E. Brown[2] and H. H. Schrenk[3]

INTRODUCTION

Inquiries and instructional work on the determination of the number concentration of dust in atmospheres known or suspected to contain pneumoconiosis (silicosis and asbestosis)-producing particulate matter indicate a need for a description of the impinger method used by the Bureau of Mines.

The impinger method consists of the collection of dust in a liquid medium and the counting under the microscope of the particles in a known portion of this liquid. The dust-collecting device is called an impinger. The dust in the air drawn through this collector at a known rate impinges at high velocity upon a smooth surface under a bubbling column of liquid. The dust is either picked up from this surface by the liquid or removed from the air as it passes through the liquid.

The impinger was devised in 1922 by Leonard Greenburg, then of the United States Public Health Service, and G. W. Smith, formerly of the Bureau of Mines[4], during a study of the comparative collecting efficiency of the main samplers in use at that time[5]. The collecting efficency of the impinger was found to be higher than that of the comparative samplers (sugar tube, Palmer apparatus, and paper filter thimble) studied. The Palmer apparatus was used by the United States Public Health Service and the sugar tube by the Bureau of Mines at the time the impinger was developed. These two samplers had well-recognized objectionable features. The collecting efficiency of the Palmer apparatus was low. In the sugar-tube method the sugar-filter bed tended to cake and crack, with also the possibility of significant contamination from the sugar. The impinger was relatively free

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[1] The Bureau of Mines will welcome reprinting of this paper provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7026."

[2] Chemist, Gas and Dust Section, Central Experiment Station, Bureau of Mines, Pittsburgh, Pa.

[3] Chief chemist, Health Division, Bureau of Mines.

[4] Greenburg, L., and Smith, G. W., A New Instrument for Sampling Aerial Dust: Rep. of Invest. 2392, Bureau of Mines, 1922, 3 pp.

[5] Bureau of Mines, U. S. Bureau of Chemistry, Research Laboratory, American Society Heating and Ventilating Engineers, and U. S. Public Health Service, Comparative Tests of Instruments for Determining Atmospheric Dusts: U. S. Public Health Bull. 144, 1925, 69 pp.

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from these objections and had the main advantages of both devices, though for some purposes the impinger has its defects also. The modified Sedgwick-Rafter counting technique[6] used in determining the amount of dust collected in the sugar tube and in the Palmer apparatus was adopted for use with the impinger.

The impinger method is widely used for determining the number concentration of dust in air. Appendix A contains a list of publications describing studies in which the impinger method was used by the Bureau of Mines and other organizations.

The method has undergone many changes since 1923. The apparatus has been modified to make it simpler and more convenient to use. The procedure for determining the amount of particulate matter has evolved from the original technique of determining the weight and number of the particles above and below 10 microns (1 micron = 0.001 mm = 0.00004 inch) in diameter to the present procedure of determining only the number of the collected particles.

IMPINGER METHOD

The impinger method consists of two main parts: Collection of the dust sample and determination of the number of particles.

COLLECTION OF THE SAMPLE

Collection of the sample involves assembling suitable apparatus, preparing it for use, and sampling.

Apparatus

The impinger apparatus consists of the impinger, suction device, collecting liquid, and accessories.

Impinger

Figure 1 shows diagrams of the various impingers used by the Bureau. Impinger "a" was used in the comparative dust-collecting efficiency study in progress when the impinger was devised. Impinger tube "b" was designed to study such features as orifice shape and size, impinging distance or distance between orifice and impinging surface, depth of immersion of orifice in the impinger liquid, and nature (smooth or rough) of impinging surface.

Impinger "c" was the first to be used in the field and the one used until the first part of 1932. The 454-ml or 16-ounce bottle was selected partly because of its convenience for use in shipping samples to the Pittsburgh Experiment Station of the Bureau of Mines for determination of the amount of collected dust.

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[6] Whipple, G. C., The Microscopy of Drinking Water: John Wiley & Sons, Inc., New York, N. Y., third ed., 1914, 409 pp.

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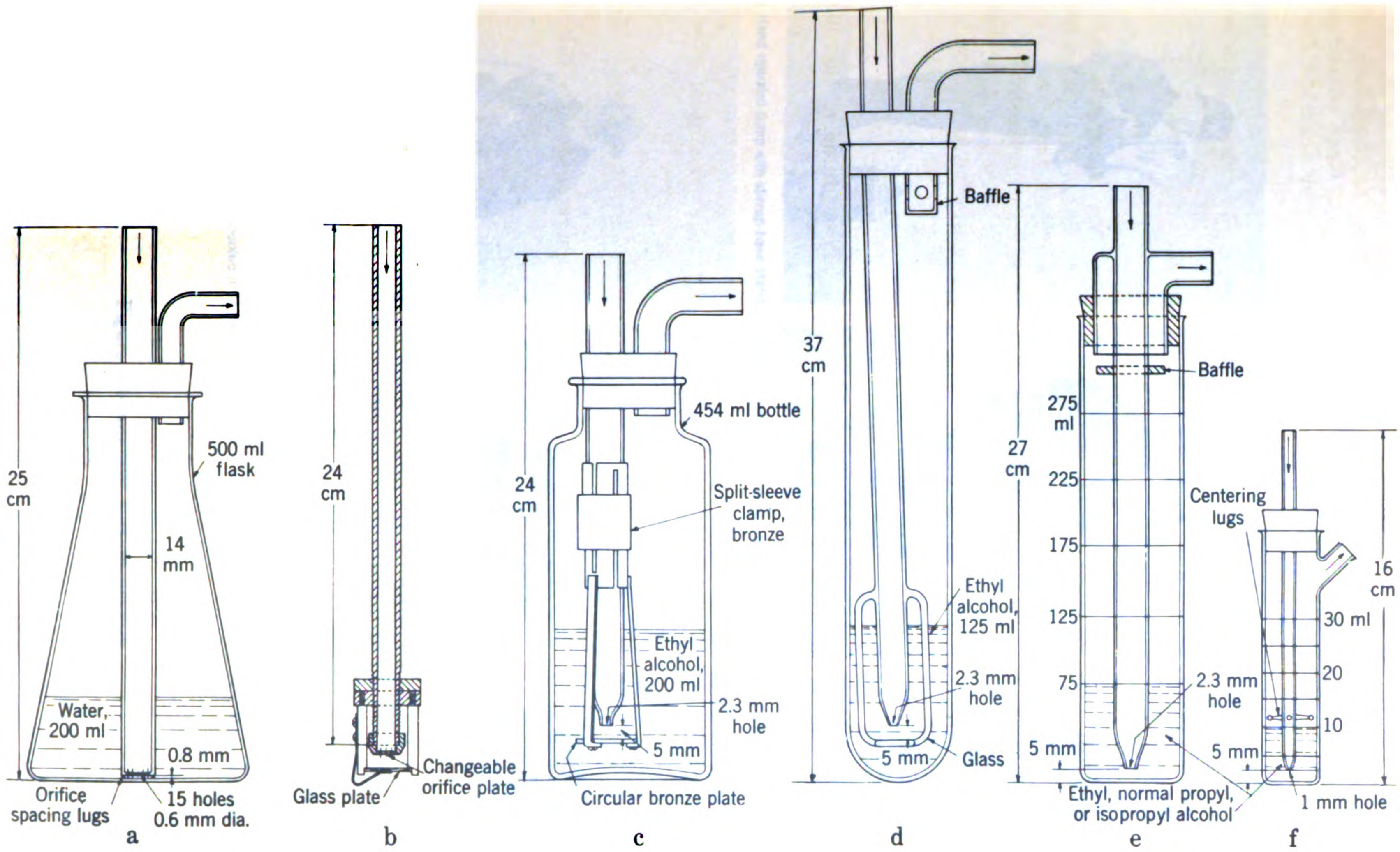
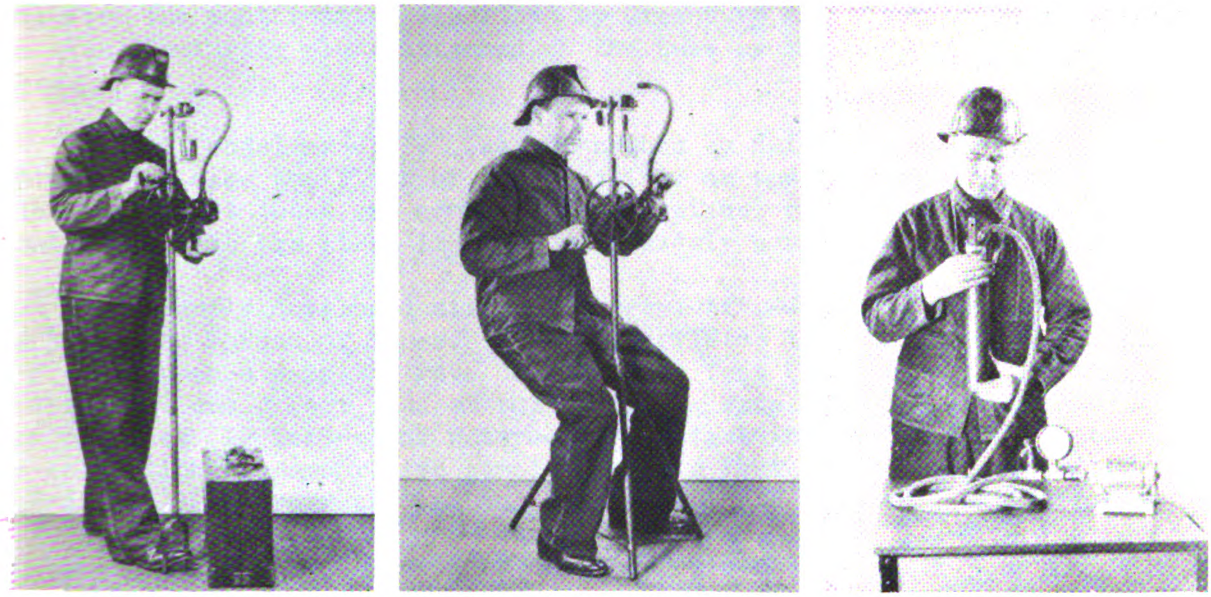
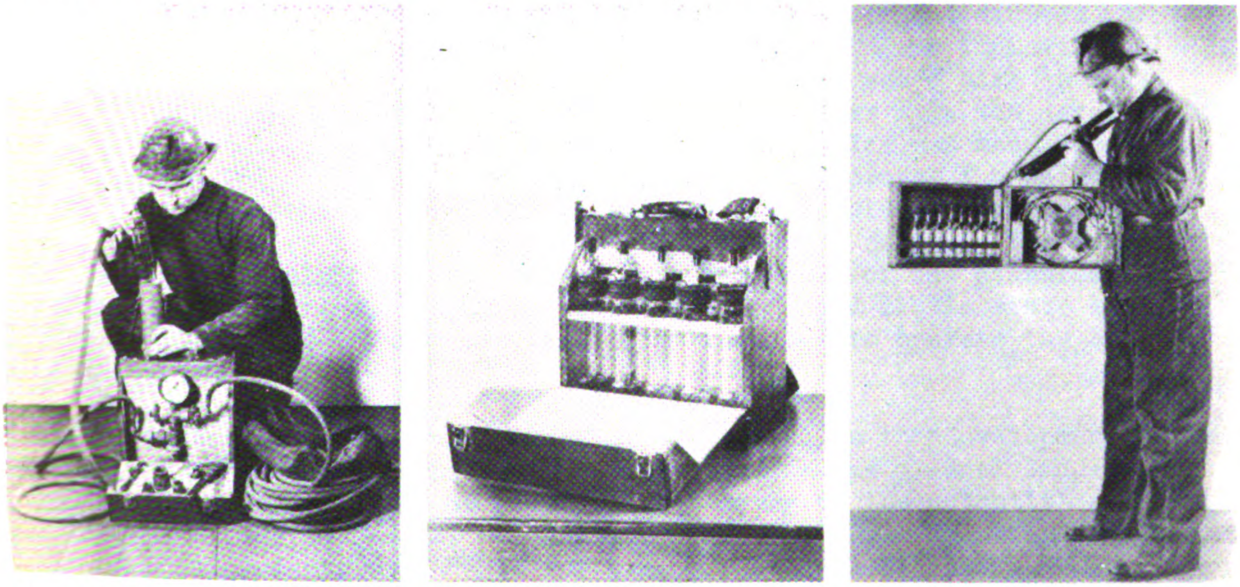


Figure 1.—Various impingers used by the Bureau of Mines.



(a) Hand-operated pump with stirrup-base stand (b) Hand-operated pump with tripod-base stand (c) Electrically-driven suction device



(d) Compressed-air ejector device mounted in impinger carrying case (e) Opposite side of impinger carrying case containing the ejector (f) Midget impinger hand-operated pump mounted in case

Figure 2.—Impinger suction devices.

Impinger "d" was designed to be attached to the worker for collection of samples from his immediate breathing zone. The impinger was made long so that the liquid would not run out when the wearer bent over. The original model was described by Badham, Rayner, and Broose[7]. Design "d" differs from the modification described by Greenburg and Bloomfield[8] in having the glass impinging plate attached to the tube by two glass legs instead of three.

The next model used, "e", was described by Hatch, Warren, and Drinker[9]. Impinger "e" uses the floor of the container as the impinging surface, the inlet and outlet tubes are combined in one piece, and the container is graduated. This was the first impinger made widely available commercially.

The recently developed midget impinger, "f",[10] is the one now used mainly by the Bureau of Mines. It has an orifice 1 mm in diameter instead of 2.3 mm, uses a sampling rate of 0.1 cubic foot (2.83 liters) per minute instead of 1 cubic foot, and at this sampling rate has a resistance to air flow of 30 cm (12 inches) of water-column height instead of about 90 cm. The collection of comparative samples by this impinger and the preceding one, "e," is still in progress, and the results to date have been satisfactory.

Impinger Suction Devices

Figure 2 shows the present impinger suction device (f) used by this Bureau and various devices that preceded it. Hand-operated devices (a) and (b) were designed for use in the first field work with the impinger in 1923. The lack of sources of power (as electricity or compressed air) in many potential sampling locations in the mineral industries made the development of a self-contained unit essential. The suction device was made from a small commercial air blower specially machined to decrease the weight, a 10.7 to 1 gear mechanism, two crank handles, and revolution counter. The stands were made of tubing attached together by slip joints. The tripod base stand had a bicycle seat. Cases were designed for the disassembled outfit and accessories. These outfits have been used little since 1932. The main objections to them are the energy required to operate the blower and the weight.

Electrically driven suction devices were used in the development of the impinger but have never been used to any extent in the mineral industries mainly because of the lack of electricity in many of the potential sampling places. Device (c) is an electrically operated suction device that has been used to a limited extent. Many other electrically operated devices have been used, some of which have been assembled by the users[11] while others are commercially available.

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[7] Badham, C., Rayner, H. E. G., and Broose, H. D., Dust Sampling in Sydney Sandstone Industries: Report of Director-General of Public Health, New South Wales, for 1927, Sydney, 1929, pp. 74-101.

[8] Greenburg, L., and Bloomfield, J. J., The Impinger Dust-Sampling Apparatus as Used by the United States Public Health Service: U. S. Public Health Repts., vol. 47, 1932, pp. 654-675.

[9] Hatch, T., Warren, H., and Drinker, P., Modified Form of the Greenburg-Smith Impinger for Field Use, With a Study of Its Operating Characteristics: Jour. Ind. Hyg., vol. 14, 1932, pp. 301-311.

[10] Littlefield, J. B., Feicht, F. L., and Schrenk, H. H., Bureau of Mines Midget Impinger for Dust Sampling: Rep. of Invest. 3360, Bureau of Mines, 1937, 4 pp.

Figure 2 (d) shows a compressed-air ejector suction device that has been used widely since its description by Hatch, Warren, and Drinker[12]. Figure 3 shows details of the device. The ejector is a No. 2 Hancock type. This arrangement will draw 28.3 liters of air per minute through the large impinger (models "c", "d", or "e" in fig. 1) when the compressed air is within the pressure range 30 to 75 pounds per square inch. The stated free air consumption is about 50 cubic feet per minute. This device may be assembled readily from standard parts or obtained commercially. The impinger outfit shown in figures 2 (d) and (e) consists of a case (designed by the Anaconda Copper Mining Co., Butte, Mont.) containing the ejector and five model "e" impingers. A knapsack (similar to that used by miners in carrying powder) is used for carrying tubing, holster, wrenches, pipe fittings, and other accessories.

Figure 2 (f) shows the impinger pump now used[13], complete with case, several midget impingers, and carrying strap. In use, the case is closed. The hand-operated pump draws air at the rate of 2.83 liters per minute through the midget impinger at a crank speed of about 60 r.p.m. The energy required to operate the pump is small (1/150 horsepower). The design of self-contained spring- and electrically-operated suction devices is being considered. The vacuum at the sampling rate is 12 inches of water. A vacuum gage is used to indicate this vacuum and, consequently, the proper crank speed. The weight of this impinger outfit is less than 15 pounds. Several commercial organizations are planning to market devices of this type.

Impinger Liquid

Distilled water was used as the collecting liquid during the laboratory development work on the impinger. The first field use of the impinger revealed that because of solubility of even siliceous dusts, water could not be used for samples not quantitated within about 24 hours after collection[14]. Until 1932, impinger samples collected in the field were shipped to the experiment station at Pittsburgh, where the amount of collected dust was determined. Thus, there was an interval of several days between collection and determination. Ethyl alcohol was selected as the collecting liquid after experiments showed no evidence of solubility not only of

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[11] Greenburg, L., and Bloomfield, J. J., Work cited (footnote 8).

[12] Hatch, T., Warren, H., and Drinker, P., Work cited (footnote 9).

[13] Littlefield, J. B., and Schrenk, H. H., Dust Sampling with the Bureau of Mines Midget Impinger, Using a New Hand-Operated Pump: Rept. of Invest. 3387. Bureau of Mines, 1938, 4 pp.

[14] Myers, W. M., Solubility of Finely Divided Rock Dusts in Water, Kerosene, and Alcohol: Rept. of Invest. 2548, Bureau of Mines, 1923, 6 pp

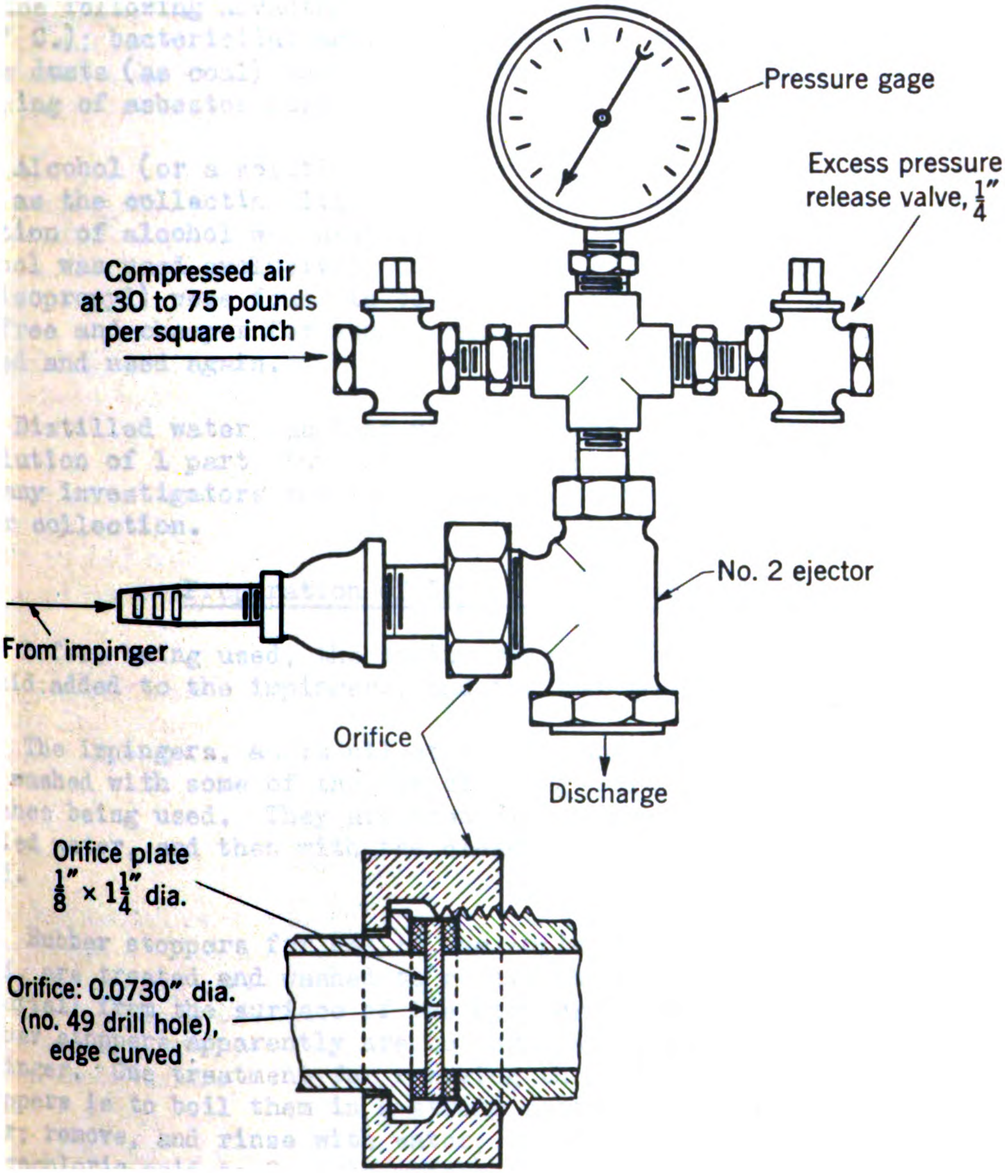
Pressure gage
Excess pressure release valve, $\frac{1}{4}''$
Compressed air at 30 to 75 pounds per square inch
No. 2 ejector
From impinger
Orifice
Discharge
Orifice plate $\frac{1}{8}'' \times 1\frac{1}{4}''$ dia.
Orifice: 0.0730" dia. (no. 49 drill hole), edge curved

Figure 3.–Ejector flowmeter unit and detail of orifice and mounting.

siliceous dust (chert) but also of limestone dust even after 28 days. The collecting efficiency of impingers using alcohol was found to be the same as for those using water. The evaporation rate of alcohol was found to be high (about 2.4 ml per minute of sampling) but not high enough to render its use impractical. In addition to freedom from solution effects, alcohol has the following advantages over water: Much lower freezing point (about -114° C.); bactericidal action (prevents growth of bacteria); wets and retains dusts (as coal) that are difficult to wet by water; and prevents the clumping of asbestos dust[15].

Alcohol (or a solution of 1 part alcohol to 3 parts water) has been used as the collecting liquid in the field work of the Bureau. The aqueous solution of alcohol was used before 1932 for collecting coal dust. Ethyl alcohol was used exclusively until about 1936, when propyl alcohols (normal and isopropyl) were found to be equally satisfactory. Propyl alcohols are tax-free and cheaper for nongovernmental users. The alcohol may be distilled and used again.

Distilled water has been used for most dusts, except coal (for which a solution of 1 part ethyl alcohol to 3 parts distilled water has been used), by many investigators who make determinations on the samples within 24 hours after collection.

Preparation of Impinger Apparatus for Use

Before being used, the impingers are washed, the stoppers treated, the liquid added to the impingers, and the impinger suction device calibrated.

The impingers, as is all other glassware used in the impinger method, are washed with some of the new cleaning compounds and water, suitable brushes being used. They are then rinsed thoroughly with tap water, distilled water, and then with the clean (relatively dust-free) liquid to be used.

Rubber stoppers for use in the impinger, especially since alcohol is used, are treated and washed to remove the particulate matter (filler material) from the surface of the stopper. Black-rubber and synthetic-rubber stoppers apparently are better than gray-rubber ones for use in the impinger. One treatment for removing the particulate matter from the black stoppers is to boil them in a strong sodium hydroxide solution for about an hour; remove, and rinse with water; immerse in an acid solution (1 part hydrochloric acid to 2 parts water) for a few minutes; remove and scrub with cleaning agent and water; and rinse with water and then with the impinger liquid. New stoppers and those that have not been used for several months are given this treatment. Particulate matter apparently has a tendency to work out of the stoppers.

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[15] Fulton, W. B., Houtz, R. L., Dooley, A., and Matthews, J. L., Asbestosis - Part I: The Collection and Counting of Dust Encountered in Asbestos Fabricating Plants: Commonwealth of Pennsylvania, Dept. of Labor and Industry, Special Bulletin No. 37, 1934, 9 pp.

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A 5-gallon glass bottle with siphon is convenient for storing clean impinger liquid and dispensing into the impinger. Approximately 75 ml of liquid usually is added to the large impingers and 10 ml to the midget impingers. The stopper containing the impinger tube is inserted tightly into the flask after the orifice has been adjusted (if necessary) to a 5-mm distance above the bottom of the flask. A covering (as several layers of friction tape) is used over the groove at the junction of the flask and stopper to prevent contamination of the sample when the stopper is removed. The openings into the impinger are closed with appropriate rubber stoppers. Each container is numbered by scratching or etching.

The impinger suction device is calibrated to determine the rate at which it pulls air through the impinger as used in actual sampling. This calibration is done at frequent enough intervals to eliminate any question of the sampling rate.

For calibration, the impinger outfit is assembled as for sampling (with the same kind and amount of liquid and the same connecting hose used between the impinger and suction device), but in addition, the inlet of the impinger is connected by a short length of rubber tubing to the outlet of a gas-measuring device, as a 5-light dry gas meter for any impinger or a wet meter for the midget impinger. Determinations of the time required for several complete revolutions of the meter dial are made until the results of two consecutive tests agree within about 1 percent. Dirt in the orifice is a common cause for low flows from the compressed-air device.

Equipment for determining sampling time, for making observations on air conditions[16] (temperature, humidity, and direction and velocity of air currents), and for recording data is needed in sampling. Appendix B contains a list of such equipment.

Sampling

The usual purpose of sampling is to determine the dust concentration to which the workers are exposed throughout the working day. This requires sampling during representative operations. The nature and number of the dust-generating and dust-disseminating processes, location and number of exposed persons, kind of work done by the workers, characteristics of working places, and atmospheric conditions (particularly ventilation or air movement) in the working places should be considered in sampling.

Samples should be collected from the breathing zone of the exposed persons. The length of the sampling period may be determined by the length of the operation, but usually should not exceed 20 minutes, owing to evaporation of the alcohol. The higher the estimated concentration, the shorter the sampling time may be, although sampling periods ordinarily are not less than 5 minutes. (See Appendix C for recording of data.)

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[16] McElroy, G. E., Engineering Factors in the Ventilation of Metal Mines: Bull. 385, Bureau of Mines, 1935, 196 pp.

DETERMINATION OF THE AMOUNT OF COLLECTED DUST

The amount of dust collected is determined by counting the particles in a known volume of the impinger liquid. This procedure may be divided as follows: Preparation of sample, preparation of the microscopic arrangement, and counting of the particles.

Preparation of Sample for Examination under Microscope

The outside of the impinger is cleaned carefully before any of the stoppers are removed. The removal of the stoppers is one of the important stages where especial care must be exercised to prevent contamination of the sample. After removal of the small stoppers, the stopper holding the impinger tube is loosened and the tube raised so that it is just out of the liquid. The inside of the tube and all other parts of the tube and stoppers originally inside of the flask are rinsed with clean liquid, which is allowed to drain into the flask. Sufficient clean liquid is then added to the impinger to bring the liquid up to the next graduation (see fig. 1 "e" and "f"). The flask is then closed by solid stoppers.

Almost any counting cell of known depth may be used. The most common cells, Sedgwick-Rafter type[17], are 1 mm in depth and about 1 ml in capacity. Cells deeper than 1 mm are rarely used, as the time required for the dust particles to settle to the floor of the cell is unduly long. The use of shallower cells is not particularly satisfactory for dilute impinger samples, as the volume of liquid in which counts are made is small, and consequently few particles are present in each field. The capacity of cells is not important, as the depth of the cell and the area in which counts are made outlines the volume of liquid examined. Cells may be purchased from optical companies or large laboratory supply houses or they may be made.

New counting cells are cleaned by scrubbing them with any of the new cleaning agents and water, using a camel-hair brush; rinsing with tap water, distilled water, and then clean alcohol (ethyl, isopropyl, or normal propyl); wiping with a clean, soft, lintless cloth; and brushing off loose dust with a dry camel-hair brush. After use, the cell is emptied, rinsed by a stream of clean alcohol, and immersed in a beaker of clean alcohol, where it is allowed to remain until used.

The cell is prepared for filling by wiping dry, brushing off loose dust, and placing the cover slip (diagonally on rectangular cells) so that there are openings for the liquid to enter and the air to escape from the cell. The sample is shaken thoroughly to distribute the dust uniformly throughout the liquid, and a pipette is flushed out two or three times with the liquid before the cell is filled. The flask is shaken for about a half minute just before the sample is withdrawn. During withdrawal of the sample, the tip of the pipette is slowly drawn from near the floor of the flask up through the liquid to obtain a representative sample. The liquid is allowed to drain into one opening of the cell so the air has a chance to escape; otherwise,

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[17] Whipple, G. C., Work cited (footnote 6).

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bubbles may form in the cell (small bubbles are not objectionable, provided they do not come close to the field examined under the microscope). The coverslip is moved into place after the cell is completely filled.

The cell is allowed to stand undisturbed for a definite time to permit dust to settle to the floor of the cell before counts are begun. In the counting procedure, only those particles on or very near the floor of the cell are counted, as the motion and poor visibility of the particles suspended in the liquid renders their counting impractical if not impossible. Descriptions of the counting procedure published before its adoption in the impinger method[18] and since[19] state that (for dust suspended in water in cells 1 mm deep) the settling time should be 20 minutes. Since the number of particles revealed in the counting procedure may increase with time[20], this 20-minute period (or equivalent time for samples in liquids other than water and in cells other than 1 mm deep) must be observed to obtain true impinger results. This equivalent settling time should be determined by experimentation. Samples collected in alcohol (ethyl, isopropyl, and normal propyl) and examined in cells 1 mm deep by the Bureau have been allowed to settle from 25 to 30 minutes before being counted to obtain results comparable to samples collected in water.

Preparation of Microscopic Arrangement

A recently developed microprojection arrangement[21] that yields the same impinger results as does the microscopic set-up is used in counting all impinger samples except those collected in short field studies in which the transportation and assembly of the microprojector is not practical.

Figure 4 shows a microprojector assembly. The light-tight cloth covering for the observation-booth framework and section from screen to microscope is removed to show construction details. This device projects images of dust particles in a counting cell on the stage of the microscope onto a ruled translucent screen at a magnification of 1,000 diameters. This assembly consists of an automatic feed arc lamp; heat filter; microscope with adjustable tube, mechanical stage, 16 mm or 10 x objective, and 20 x eyepiece; right-angle prism; ruled translucent screen; and remote controls between the microscope and screen. (See Appendix B for a complete list of equipment needed in counting impinger samples.) An arc lamp is the

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[18] Selvig, W. A., Osgood, F. D., and Fieldner, A. C., Collection and Examination of Rock Dust in Mine Air: Rep. of Invest. 2122, Bureau of Mines, 1920, 7 pp.

[19] Bloomfield, J. J., and DallaValle, J. M., The Determination and Control of Industrial Dust: U. S. Public Health Bull. 217, 1935, 167 pp. (p.41).

[20] Kronenberg, M. H., Setterlind, A. N., and McClure, C. H., Investigation of Factors Influencing Dust Determinations Made by the Impinger Method: Jour. Ind. Hyg. and Tox., vol. 19, 1937, pp. 198-203.

[21] Brown, C. E., Baum, L. A. H., Yant, W. P., and Schrenk, H. H., Microprojection Method for Counting Impinger Dust Samples: Rep. of Invest. 3373, Bureau of Mines, 1938, 9 pp.

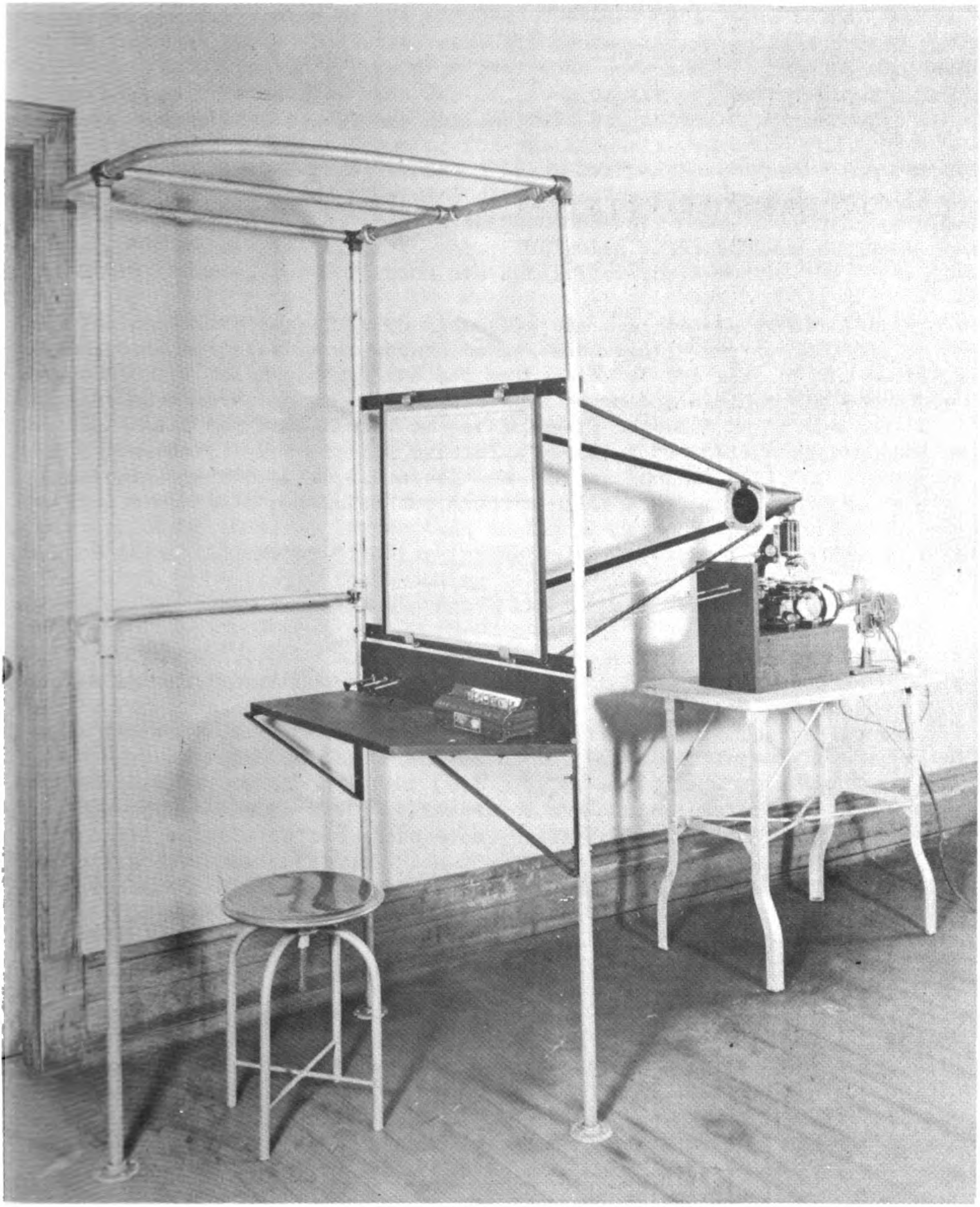

Figure 4.—Microprojector assembly. The light-tight covering is removed to show construction details.

only satisfactory source of illumination that has been found to be intense enough for this work. Direct-current lamps are preferable to those of alternating current. The same type of microscopic equipment is used as employed in the microscopic procedure. The use of apochromatic objective, compensated eyepiece and aplanatic substage condenser is suggested if the microprojector is also to be used for research or for particle-size work[22]. The screen consists of a thin (32-gage) sheet of light ivory-colored dental dam rubber clamped between two panes of window glass free from apparent defects. The rulings, which outline the area in which counts are made, are drawn on one of the panes of glass with black enamel. The ruled area is 50-cm square divided into 10-cm squares, some of which are subdivided further.

The magnification of 1,000 diameters was selected to render the images of the dust particles large enough to be seen readily and to facilitate calibration of the screen rulings and estimation of the size of the particles. The same objective, 16 mm or 10 x, is used as in the microscopic procedure to assure that the same number of particles is revealed as by the microscopic procedure. Most of the particles revealed by the impinger method are approximately a micron in diameter. At a magnification of 1,000 diameters, the images of these particles are about a millemeter, or 0.04 inch, in diameter or about 10 times larger than in the microscopic procedure. Observation of these millimeter-diameter images on the microprojection screen with both eyes is much easier than looking through the microscope with one eye at images one-tenth as large against a light-field background.

Information for the most compact microprojection set-up required to produce a magnification of 1,000 diameters on a 50-cm square screen using a 16-mm or 10-x objective on the microscope was obtained by projecting the image of a stage micrometer onto a 50-cm-square screen. The screen was moved back and forth until the images of the 0.1-mm rulings of the stage micrometer were 1,000 times larger (0.1 x 1,000 = 100 mm = 10 cm). This process was repeated with the tube length of the microscope at 160 mm and with different eyepieces in the microscope, until the assembly with the shortest projection distance (distance from microscope to screen) was determined. This projection distance for the equipment used was found to be 117 cm (46 inches), obtained by using a 20-x eyepiece. Higher-powered eyepieces gave 1,000-diameter magnification at shorter distances, but the projected circle of light did not cover the screen.

The equipment used in counting by the microscopic procedure consists of microscopic stand with adjustable tube, 16-mm or 10-x objective, 7.5-x or 10-x eyepiece, eyepiece micrometer, source of illumination, and accessories.

The eyepiece micrometer is used to outline the area in which the particles are counted. The most common micrometer used (Whipple disk) has a square ruling divided into 100 equal squares, one of which is further ruled

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[22] Brown, C. E., and Yant, W. P., The Microprojector for Determining Particle-Size Distribution and Number Concentration of Atmospheric Dust: Rep. of Invest. 3289, Bureau of Mines, 1935, 8 pp.

Page [23] recently described a modification of this micrometer having one-fourth the area, or the area usually used in counting impinger samples. These micrometers are calibrated against a stage micrometer. With the micrometer resting with ruled side down on the diaphragm in a 7.5-x or 10-x eyepiece, and the microscope focused on the rulings on a stage micrometer, the tube of the microscope is adjusted up or down until the area of the image of the Whipple ruling corresponds to an area one millimeter square under the microscope, or until the area of the image of the Page ruling corresponds to an area one-quarter as large (0.25 mm^2). The number of contaminating particles on the micrometer ruling is kept below about 8 for the Whipple disk and 2 for the Page modification. Micrometers having more particles are removed from the eyepiece, cleaned with lens paper, and brushed with a camel-hair brush.

Counting

The general procedure for counting the particles in the counting cells is the same in both the microprojection and microscopic techniques. The counting cell, after it has been allowed to remain undisturbed for the proper settling time, is transferred to the stage of the microscope. The microscope is focused on the dust particles on and near the floor of the cell. The floor of the cell is located by focusing on the contamination in the corner or near the edge of the cell. All the visible particles in measured (by screen or micrometer rulings and depth of cell) volumes of the liquid are counted in five (one near the center and one between each corner and the center) places in each of two cells from each sample. The microscope is focused continuously during counting to make the particles go in and out of focus, thus rendering them easier to see and to assist in distinguishing between particles in the cell and on the eyepiece micrometer or screen. Ordinarily the microscope is not focused up through the liquid to try to bring the particles suspended in the liquid into focus, because experience has shown that the motion and poor visibility of these particles render their enumeration impracticable if not impossible. Impinger samples so concentrated that the particles, as seen under the miccoscope, are close enough together to render counting difficult are diluted to reduce the count to a convenient value. This operation makes the use of the impinger practicable in air containing any concentration of particulate matter, no matter how high, a condition not true of many other kinds of samplers. Blank or control counts are made on the clean impinger liquid. The blank counts are subtracted from the counts on the samples.

Table 1 gives the details of the microprojection and microscopic techniques for counting samples.

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[23] Page, R. T., Note on a New Ocular Micrometer for Use in Dust Counting: U. S. Public Health Rep., vol. 52, 1937, pp. 1315-1316.

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Table 1. - Features of the microprojection and microscopic procedures for counting impinger samples

Feature	Microprojection technique	Microscopic technique
Sample container	Counting cell	Counting cell
Objective used on microscope	16 mm or 10 X	16 mm or 10 X
Kind of illumination	Light field	Light field
Magnification of dust particles, diameters.	1,000	About 100[a]
Observation of images	On translucent screen with both eyes	Through microscope with one eye
Area outlined by -	Rulings on screen	Micrometer in eyepiece of microscope
Field or area in which counts are usually made, cm^2................................	500	25[b]
Volume of impinger liquid in which particles are counted, mm^3	0.05[c]	0.25[c]
Diameter of images of particles 1 micron in diameter	1 mm 0.04 in.	0.1 mm 0.004 in.
Maximum number of images per field that can be counted conveniently....................	1,500[d]	75
Maximum number of images per field that should be present in blank or control sample	2	10

[a] The calibration of the microscopic arrangement so that the length of the image of the 1-mm ruling on the stage microscope corresponds to the image of the side of the Whipple micrometer does not indicate, as is occasionally supposed, that the magnification of the set-up is 100 diameters. The exact magnification can be determined by projecting the image of the stage micrometer ruling on a screen located 250 mm or 10 in. from the top lens of the eyepiece, measuring the exact length of the image of the ruling, and dividing this length by the actual length of the ruling.

[b] This is the apparent size of the image of one-quarter of the Whipple micrometer and of the total area of the Page modification in a microscopic set-up having a magnification of 100 diameters.

[c] These values hold for counting cells 1 mm in depth.

[d] This value indicates that impinger samples 100 times more concentrated $(\frac{5 \times 1500}{75} = 100)$ can be counted by the microprojection technique than should be counted by the microscopic procedure without dilution. The ability of the microprojection procedure to work with more concentrated samples than the microscopic technique leads to saving of the time required in making secondary dilutions, to less chance for contamination since one operation is eliminated from some of the determinations, and to greater accuracy in some of the results since the counts (and errors in counts) are not multiplied by large dilution factors.

The small rulings (5-cm squares and 2-cm by 5-cm rectangles) are used in counting concentrated samples by the microprojection technique, and a smaller field (less than 500 cm^2) is used for such samples.

The counts per field in a cell may vary as much as ± 25 percent from the average count per field for the cell, but the average counts per field for the two cells from each impinger sample should not differ by more than 3 percent for average counts up to 20 particles per field, by more than 4 percent for counts from 20 to 40 particles, by more than 5 percent for counts from 40 to 75 particles, or by more than 10 percent from the low count for counts above 75 particles per field. When the variations are greater than these limits, additional cells should be filled and counted. Bacterial contamination or aggregation may be the explanation for erratic results on samples in water. Contamination by particulate matter from rubber stoppers may cause erratic results on samples collected in alcohol.

Samples too concentrated to be counted are diluted. A measured portion (1, 2, 5, or 10 ml) is transferred by means of a pipette to a volumetric flask or graduated impinger flask and diluted with clean liquid to a desired volume (estimated from an examination or partial count on the concentrated sample). The dilution factor or result of dividing the final diluted volume by the portion diluted is calculated.

Data usually recorded on counting of each sample are: Sample number; name or initials of person making the count; initial volume, dilution, and final volume (initial volume x dilution factor) of impinger sample; settling time; size of field; counts per field in each of the two cells; average count per field for each cell; blank or control average count per field; net (actual-control) average count per field for the sample; calculated concentration of dust in the sampled air (see following); and remarks on counting. A record with all changes, is kept of the counting assembly and procedure.

The concentration of dust in millions of particles per cubic foot of sampled air is calculated from the average net count per field or measured (by area in which counts are made and cell depth) volume, final volume of liquid, and volume of air sampled. The method of calculating may be illustrated as follows:

$$\frac{\text{Count x final volume of impinger liquid, mm}^3}{\text{Volume of liquid in which counts made, mm}^3 \text{ x volume of air sampled, ft}^3 \text{ x } 1{,}000000} =$$

millions of particles per cubic foot of sampled air.

- -

Count = average net count per field or per volume of liquid in which counts made.

Final volume of impinger liquid = initial volume of liquid x dilution factor.

1 ml = 1,000 mm^3.

Volume of liquid in which counts made = area of cell in which counts made x cell depth.

Air sampled = sampling rate x length of sampling period.

DISCUSSION

Table 2 contains impinger values of some tentative figures on the probable maximum safe concentration of dust in the air of certain industries. These values were determined by correlating results of the determination of the concentration of dust in various representative atmospheric environments in the particular industry, with the results of physical examinations of the workers; they may be used, at least tentatively, as guides in establishing limits for control work; but care should be exercised in using these figures to estimate from the free silica content the probable safe limit for dusts other than those encountered in these industries, as other factors, such as particle size distribution and the nature of constituents accompanying the free silica, as well as numerous other conditions, may be quite important.

The articles listed in Appendix A contain impinger results useful for comparative purposes; these articles indicate that the dust concentration can be kept below what are believed to be the maximum safe limits by practical means. Some large industrial establishments have based their dust-control work on a maximum concentration of five million particles per cubic foot.

Table 2. - Probable maximum safe dust concentrations as indicated by the impinger method

Industry	Kind of dust	Free silica percent	Probable safe concentration, millions of particles per cubic foot
Granite cutting	Granite	35	9 - 20[a]
Cement manufacturing	Cement	7	10 - 20[b]
Anthracite coal mining	Anthracite coal	5	50[c]
Do.	do.	13	10 - 15[c]
Do.	Sandstone and shale	35	5 - 10[c]

[a] See reference 2b in Appendix A for original data.
[b] See reference 2c in Appendix A for original data.
[c] See reference 2i in Appendix A for original data.

The impinger method indicates the approximate number concentration of those insoluble (in the impinger liquid) microscopically visible solid particles in the sampled air. The collecting efficiency of the impinger has been found to be well over 90 percent for dusts[24], [25], [26], consisting of particles larger than about 0.5 micron in diameter. The exact size of the smallest particles revealed by the microscopic procedure is not known, but there are indications that it varies from about 0.5 to 1.5 microns, depending upon the optical properties of the particles.

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[24] Bureau of Mines, U. S. Bureau of Chemistry, Research Laboratory American Society Heating and Ventilating Engineers, and U. S. Public Health Service, Work cited (footnote 5.)

[25] Hatch, J., Warren, H., and Drinker, P., Work cited (footnote 9).

[26] Littlefield, J. B., Feicht, F. L., and Schrenk, H. H., Collecting Efficiency of Impinger for Lead Dusts and Fumes: Rep. of Invest. 3401, Bureau of Mines, May 1938, 9 pp.

Impinger results are empirical, or relative, and not absolute. They do not indicate the total concentration of particles in the sampled air - a value that is indeterminate by known means and probably of little, if any, value. The particles in the air are extremely complex in composition and variable in size, shape, and other properties. The particles or, better, particulate masses may consist of solid, liquid, or a combination of solid and liquid matter. They may be single particles or a collection of particles held together either tightly or loosely. These masses may range in size from the visible, through the microscopic, and possibly below the ultra-microscopic range, into the molecular region. These masses may be electrically neutral or charged positively or negatively.

In interpreting impinger results and in attempting to correlate the results of other dust-sampling methods with impinger results, the preceding discussion of the nature of atmospheric particulate matter and the following discussion of some features of the impinger method should be considered. The collecting efficiency of the impinger is low for particles smaller than about a half micron in diameter, as has been found with tobacco smoke and lead and magnesium oxide fumes. There are indications that particles may be fractured and aggregates broken up by the impingement in sampling[27/]. Some of the particulate masses may be dissolved in the impinger liquid. All the particles visible in the microscopic set-up used are not revealed in the regular counting procedure, as may be shown by recounting the sample after additional settling time. Examination by dark-field microscopy reveals many particles not rendered visible by the regular light-field procedure.

SUMMARY

The procedure used by the Bureau of Mines in determining by the impinger method the number concentration of dust in industrial atmospheres known or suspected to contain pneumoconiosis-producing material is described.

[27/] Ficklen, J. B., and Goolden, L. L., The Behavior of Certain Dusts under Mechanical Impingement: Science, vol. 85, 1937, pp. 587-588.

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APPENDIX A - BIBLIOGRAPHY OF STUDIES IN WHICH THE IMPINGER METHOD WAS USED

1. Publications of the Bureau of Mines

(a) Forbes, J. J., and Emery, A. H., Sources of Dust in Coal Mines: Rept. of Investigations 2793, Bureau of Mines, 1927, 17 pp.

(b) Littlefield, J. B., and Schrenk, H. H., Relation of Dust Concentration to Depth of Hole During Wet Drilling: Rept. of Investigations 3369, Bureau of Mines, 1938, 5 pp.

(c) Brown, C. E., and Schrenk, H. H., Effect of Angle of Drilling on Dust Dissemination: Rept. of Investigations 3381, Bureau of Mines, 1938, 7 pp.

(d) Brown, C. E., and Schrenk, H. H., Control of Dust from Blasting by a Spray of Water Mist: Rept. of Investigations 3388, Bureau of Mines, 1938, 13 pp.

(e) Brown, C. E., and Schrenk, H. H., Relation of Dust Dissemination to Water Flow through Rock Drills: Rept. of Investigations 3393, Bureau of Mines, 1938, 6 pp.

2. Publications of the United States Public Health Service

(a) Greenburg, L., Studies on the Industrial Dust Problem. III. Comparative Field Studies of the Palmer Apparatus, the Konimeter, and the Impinger Methods for Sampling Aerial Dust: U. S. Pub. Health Repts., vol. 40, July 31, 1925, pp. 1591-1603.

(b) Thompson, L. R., Brundage, D. K., Russell, A. E., and Bloomfield, J. J., The Health of Workers in Dusty Trades. I. Health of Workers in a Portland Cement Plant: U. S. Pub. Health Bull. 176, April 1928, 138 pp.

(c) Russell, A. E., Britten, R. H., Thompson, L. R., and Bloomfield, J. J., The Health of Workers in Dusty Trades. II. Exposure to Siliceous Dust (Granite Industry): U. S. Pub. Health Bull. 187, July 1929, 206 pp.

(d) Thompson, L. R., Russell, A. E., and Bloomfield, J. J., The Health of Workers in Dusty Trades: General Statement and Summary of Findings. III. Exposure to Dust in Coal Mining. IV. Exposure to Dust in a Textile Plant. V. Exposure to the Dusts of a Silverware-Manufacturing Plant. VI. Exposure to Municipal Dust (Street Cleaners in New York City): U. S. Pub. Health Bull. 208, July 1933, 37 pp.

(e) Bloomfield, J. J., and Greenburg, L., Sand and Metallic Abrasive Blasting as an Industrial Health Hazard: Jour. Ind. Hyg., vol. 15, July 1933, pp. 184-204.

(f) Bloomfield, J. J., and Dreessen, W. C., Silicosis among Granite Quarriers: U. S. Pub. Health Repts., vol. 49, June 8, 1934, pp. 679-684.

(g) Dreessen, W. C., Effect of Inhaled Marble Dust as Observed in Vermont Marble Finishers: U. S. Pub. Health Repts., vol. 49, June 22, 1934, pp. 724-732.

(h) Dreessen, W. C., and DallaValle, J. M., The Effects of Exposure to Dust in Two Georgia Talc Mills and Mines: U. S. Pub. Health Repts., vol. 50, Feb. 1, 1935, pp. 131-143.

(i) Sayers, R. R., Bloomfield, J. J., DallaValle, J. M., Jones, R. R., Dreessen, W. C., Brundage, D. K., and Britten, R. H., Anthraco-Silicosis among Hard-Coal Miners: U. S. Pub. Health Bull. 221, December 1935, 114 pp.

(j) Page, R. T., and Bloomfield, J. J., A Study of Dust-Control Methods in an Asbestos Fabricating Plant: U. S. Pub. Health Repts., vol. 52, Nov. 26, 1937, pp. 1713-1727.

3. Publications of Metropolitan Life Insurance Co.

(a) Fehnel, J. W., Silicosis Among Rock Drillers, Blasters, and Excavators in New York City, Based on a Study of 208 Examinations. III. A Study of Silica Dust in Hard Rock Drilling in New York City: Jour. Ind. Hyg., vol. 11, February 1929, pp. 69-79.

(b) McConnell, W. J., and Fehnel, J. W., Health Hazards in the Foundry Industry: Jour. Ind. Hyg., vol. 16, July 1934, pp. 227-251.

(c) Lanza, A. J., McConnell, W. J., and Fehnel, J. W., Effects of the Inhalation of Asbestos Dust on the Lungs of Asbestos Workers. A Preliminary Study: U. S. Pub. Health Repts., vol. 50, January 4, 1935, pp. 1-12.

(d) Fehnel, J. W., Determination of Effectiveness of Dust-Control Measures Used in Mines: Amer. Inst. Min. & Met. Engrs. Tech. Pub. No. 637-A, 60, August 1935, pp. 12-17.

(e) Fehnel, J. W., Dust Concentration in Quarries: National Safety News, vol. 33, February 1936, p. 34.

4. Publications of Harvard School of Public Health

(a) Hatch, T., Kelley, G. S., and Fehnel, J. W., Control of the Silicosis Hazard in the Hard-Rock Industries. II. An Investigation of the Kelley Dust Trap for Use with Pneumatic Drills of the "Jackhammer" Type: Jour. Ind. Hyg., vol. 14, February 1932, pp. 69-79.

(b) Hatch, T., Fehnel, J. W., Warren, H., and Kelley, G. S., Control of the Silicosis Hazard in the Hard-Rock Industries. IV. Application of the Kelley Trap to Underground Drilling Operations: Jour. Ind. Hyg., vol. 15, January 1933, pp. 41-56.

(c) Hatch, T., and Pool, C. L., Quantitation of Impinger Dust Samples by Dark-Field Microscopy: Jour. Ind. Hyg., vol. 16, May 1934, pp. 177-191.

5. Publications of Others

(a) Smyth, H. F., and Smyth, Jr., H. F., Spray-Painting Hazards as Determined by the Pennsylvania and the National Safety Council Surveys: Vitreous Enamel Spraying and Silicosis: Jour. Ind. Hyg., vol. 10, June 1928, pp. 205-212.

(b) Gardner, L. U., and Cummings, D. E., Studies on Experimental Pneumonokoniosis. VI. Inhalation of Asbestos Dust: Its Effect upon Primary Tuberculosis Infection: Jour. Ind. Hyg., vol. 13, February 1931, pp. 65-81, and March 1931, pp. 97-114.

(c) Smith, A. R., A Study of Granite Cutting and Granite Cutters in the Vicinity of New York City: Amer. Jour. Pub. Health, vol. 24, August 1934, pp. 821-834.

(d) Fulton, W. B., Dooley, A., Matthews, J. L., and Houtz, R. L., Asbestosis. Part II. The Nature and Amount of Dust Encountered in Asbestos-Fabricating Plants. Part III. The Effects of Exposure to Dust Encountered in Asbestos-Fabricating Plants on the Health of a Group of Workers: Pennsylvania Dept. of Labor and Industry, Special Bull. 42, September 20, 1935, 35 pp.

(e) Lavender, H. M., and Lyman, G. B., Underground Methods in Dust Control: Min. Congress Jour., vol. 21, December 1935, pp. 32-34 and 40.

(f) New Rock-Drill Dust Control: Eng. News Record, vol. 119, December 30, 1937, pp. 1058-1061.

APPENDIX B - LIST OF SUGGESTED IMPINGER EQUIPMENT

Equipment for Collecting Sample of Dust

Midget impinger outfit.
Extra impingers, 6; or, as second choice,
Large impinger outfit with compressed air-ejector device (fig. 2(d) and (e)).
Extra impingers (model "e", fig. 1), 10.
Holster (for holding impinger during sampling).
Impinger intake shield (to prevent contamination from dropping into the intake).
Solid stoppers for all impingers.
Isopropyl alcohol, practical grade, 10 gallons.
5-gallon bottle with siphon.
Small glass still.
Cleaning material.
Assorted brushes.

Equipment for Collecting Sample of Dust (Cont'd)

500-ml wash bottles.
Friction tape.
Glass-scratching device (diamond point or tungsten-carbide scriber).
China-marking pencil.
5-light dry gas meter.
Stop watch.
Inexpensive wrist or pocket watch.
Data book (mining engineers' transit book).

Equipment for Determination of Atmospheric Conditions in Sampling Location

Sling psychrometer with leather case and shoulder strap.
Spare thermometers for the psychrometer, 2.
Low-speed vane anemometer with leather case and shoulder strap.
Pitot tube, 1/4 inch O. D., about 15 inches long.
U-tube water gage, with rubber tubing.
25-foot tape in case.
Aspirator bulb with hard-rubber valves and rubber tubing.
Tin or titanium tetrachloride smoke tubes, 12.

Equipment for Determination of Amount of Collected Dust

Microprojector assembly consisting of -
  Microscope stand with adjustable tube and mechanical stage with horizontal control shafts.
  16-mm or 10X objective (apochromatic preferred).
  20X eyepiece (compensated, if apochromatic objective used).
  1.4 n.a. aplanatic condenser.
  4.5 amp. or greater direct current (or 10 amp. alternating current) automatic-feed arc lamp with suitable rheostat.
  Extra carbon electrodes, 100 pairs.
  Heat filter or water cell for arc lamp.
  Projection prism for use above microscope eyepiece.
  Ruled translucent screen.
  Light shields.
  Remote controls, or, as second choice,
Microscope equipment consisting of -
  Microscope stand with adjustable tube and mechanical stage (desirable but not essential).
  16-mm or 10X objective, 7.5X or 10X eyepiece, and substage condenser.
  Microscope lamp.
  Whipple or modified Whipple eyepiece micrometer.

Equipment for Determination of Amount of Collected Dust (Cont'd)

Stage micrometer.

Sedgwick-Rafter counting cells suitable for use with alcohol, 12.

Counter, 4-place hand tally or some form of five-unit counter.

Camel-hair brushes, 1/2-inch, 4.

Lens paper.

Unweighted silk or other soft lintless cloth.

250-ml beakers and coverglasses, 4.

2-ml pipettes, 8.

10-ml pipettes, graduated, 2.

500-ml graduate or hydrometer cylinder (for holding pipettes).

50-ml volumetric flasks, 4.

200-ml volumetric flasks, 4.

Rack for holding 10 impingers.

Equipment for Recording Data

Large specially ruled book.

APPENDIX C - SAMPLING DATA

General Information for All Sampling Work

Flow sheet of operations indicating significant dust-disseminating operations.

Record of dust-control measures.

Chronological record of dust-sampling work.

Record of persons doing the dust sampling.

Description of impinger apparatus used.

Impinger calibration data.

Information on a Particular Sampling Survey

Date

Sampling Location

Mine or plant.

Location.

Details of Sampling Location (sketch)

Size (sketch).

Kind and location of dust-disseminating processes (sketch).

Conditions of surfaces (clean or dusty, dry or wet).

Information on a Particular Sampling Survey (Cont'd)

Number and location of men exposed (sketch).

Location of impinger (sketch).

Air conditions; psychrometric readings (dry-bulb and wet-bulb temperatures) (sketch).

Velocity, volume, and direction of air current (sketch).

Sampling

Purpose of sample.

Sample number (record permanent number of impinger as well as sample number marked on flask with china-marking pencil).

Actual time of beginning and end of sample.

Operations in progress during sampling.

Miscellaneous

Description of dust-control measures in use and showing evidence of prior use.

Knowledge of and attitude of exposed persons toward dust problem.

Cycle of operations, with estimated time of each per shift, in the sampling location.

Any other pertinent information.